1. PI

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2. Title of Research Grant

Science Team Participation in the ARM Program

3. Scientific Goals

The scientific goals are to interface data and models so as to obtain a better understanding of cloud-climate interactions and feedbacks.

4. Accomplishments

- Consistency tests have been applied to the measurement of total, direct and diffuse shortwave radiation at the surface as measured at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site.
- Validation of longwave atmospheric radiation models has been performed using ARM data.
- The influence of the 1998 El Nino upon cloud-radiative forcing over the Pacific warm pool has been investigated.
- Algorithm-development strategies for retrieving the downwelling longwave flux at the earth's surface have been evaluated.

5. Progress and Accomplishments

5.1. Consistency tests applied to the measurement of total, direct and diffuse shortwave radiation at the surface

Motivated by recent studies suggesting the clear-sky atmosphere absorbs more shortwave (solar) radiation than do theoretical models, we have performed two consistency tests on the data used in several of these studies. These data consist of broadband measurements of shortwave irradiance to the surface (total, direct and diffuse) taken in Oklahoma. In the absence of aerosols, Rayleigh scattering is the sole source of diffuse radiation and thus, without any unknown source of atmospheric SW absorption, the measured diffuse irradiance should not be less than that produced by a model incorporating both Rayleigh scattering and conventional atmospheric absorption. The measurements of broadband diffuse irradiance, however, exhibit considerable sub-Rayleigh behavior. On the other hand, measurements of the diffuse irradiance in narrow spectral bands, centered at 415, 500 and 608 nm, indicate no sub-Rayleigh behavior, suggesting that exhibited by the broadband measurements is probably unrealistic. Related to this is the finding that the total surface SW irradiance, when evaluated as the sum of the direct-beam irradiance (pyrheliometer) and the diffuse irradiance (shaded pyranometer) differs considerably and diurnally from the single measurement of the total irradiance by the unshaded pyranometer under conditions in which possible cosine response errors of the unshaded pyranometer have been minimized. This indicates the pyranometers' daytime offsets differ from each other, suggesting their daytime offsets likewise differ from their nighttime offsets which are nearly identical. We emphasize that these conclusions apply solely to the data for Oklahoma, and they are focused upon obtaining a better understanding of the clear-sky absorption problem that analyses of these data have raised.

5.2. Validation of longwave atmospheric radiation models using Atmospheric Radiation Measurements (ARM) data

Data taken at the ARM Program's Central Facility in Oklahoma, and processed as part of the CAGEX (Clouds and the Earth's Radiant System/ARM/Global Energy and Water Cycle Experiment) project, have been used to validate the top-of-the-atmosphere and the surface longwave radiative fluxes for two widely used radiation models: the Column Radiation Model from the National Center for Atmospheric Research Community Climate Model (CCM), and the Moderate Resolution Transmittance (MODTRAN3) radiation code. The results show that for clear skies the models slightly overestimate outgoing longwave radiation at the top of the atmosphere (OLR) and underestimate the surface downwelling longwave flux (SDLW). The accuracy of the radiation models is quite consistent with their respective levels of complexity. For MODTRAN3, for example, the OLR overestimate is 7.1 Wm^{-2} while the SDLW underestimate is 4.2 Wm^{-2}. For cloudy skies, it is emphasized that the cloud input parameters, as determined from measurements by various instruments, require careful examination and preprocessing. Spatial and temporal averaging could result in the parameters representing different volumes of the atmosphere. The discrepancy between model calculations and observations is shown to be significantly reduced through the proper choice of input parameters.

5.3. The influence of the 1998 El Nino upon cloud-radiative forcing over the Pacific warm pool

Clouds cool the climate system by reflecting shortwave radiation and warm it by increasing the atmospheric greenhouse. Previous studies have shown that in tropical regions of deep convection there is a near cancellation between cloud-induced shortwave cooling and longwave warming. The present study investigates the possible influence of the 1998 El Nino upon this near cancellation for the tropical western Pacific's warm pool, and this was accomplished by employing satellite radiometric measurements (Earth Radiation Budget Experiment, and Clouds and the Earth's Radiant Energy System). With the exclusion of the 1998 El Nino, we also find near cancellation between the shortwave and longwave cloud forcings; the shortwave cooling slightly dominates the longwave warming, and there is considerable interannual variability in this modest dominance. For the strong 1998 El Nino, however, there is a substantially greater tendency towards net radiative cooling, and the physical mechanism for this appears to be a change in cloud vertical structure. For normal years, as well as for the weaker 1987 El Nino, high clouds dominate the radiation budget over the warm pool. In 1998, however, the measurements indicate the radiation budget is partially governed by middle-level clouds, thus explaining the net cooling over the warm pool during the 1998 El Nino as well as emphasizing differences between this event and the weaker 1987 El Nino.

5.4. Algorithm-development strategies for retrieving the downwelling longwave flux at the earth's surface

Algorithm-development strategies for retrieving the surface downwelling longwave flux (SDLW) have been formulated based on detailed studies with radiative transfer models and observational data. The model sensitivity studies are conducted with the Column Radiation Model (CRM) from the National Center for Atmospheric Research Community Climate Model Version 3 (CCM3) and the Moderate Resolution Transmittance (MODTRAN) radiation model. The studies show that the clear-sky SDLW can be largely determined from only two parameters: the surface upwelling longwave flux and the total precipitable water vapor. Cloudy-sky sensitivity tests show that the cloud-base height is an important factor in determining the SDLW, especially for low clouds. However, when considering broken clouds as occur in reality, column cloud liquid water seems to be a preferable parameter for use in the cloudy-sky algorithm.

Observational data from the ARM Program at the SGP Oklahoma Central Facility and the Tropical Western Pacific (TWP) site on Manus Island are used in deriving and validating an illustrative algorithm. The observations show similar relations as found in the model sensitivity tests, and suggest that a single algorithm could be applicable for both clear and overcast conditions as well as to diverse geographical locations. This algorithm generality is further demonstrated by using simulated data from CCM3. When a single algorithm is applied to six geographically diverse regions, the SDLW bias errors range from -3.5% (-10.6 Wm^{-2}) to 2.1% (7.9 Wm^{-2}), while RMS errors are between 1.4% and 5.5% for the regions chosen. The algorithm is not, however, applicable when low-level ice clouds are present.

6. Figure attachments

Figure 1: An algorithm has been developed for determining the surface downward longwave radiation (SDLW) through a regression fit to data obtained during the first six IOPs at the ARM Southern Great Plains site. This figure shows the comparison of the algorithm to data taken during nine subsequent IOPs which, unlike the first six IOPs, contain data taken during winter. The single algorithm seems to work equally well for both all-sky and clear-sky conditions.

Figure 2: The same as Figure 1, but with the algorithm compared to data taken during a six month period at the ARM TWP site on Manus Island. This suggests that the algorithm may have broad geographical applicability.

Figure 3: This compares four longwave column radiation models to the OLR and the SDLW as measured at the ARM Southern Great Plains site when a single-layered cloud is present. The column radiation models consist of the Fu-Liou code, the models contained within versions 2 and 3 of the NCAR Community Climate Model (CCM2 and CCM3), and version 3 of MODTRAN.

7. Publications

1. M. S. Croke, R. D. Cess, and S. Hameed, 1999: Regional cloud cover change associated with global climate change: Case studies for three regions of the United States, *J. Climate,* **12**, 2128-2134.
2. R. D. Cess, T. Quian, and M. Sun: Consistency tests applied to the measurement of total, direct and diffuse shortwave radiation at the surface, *J. Geophys. Res.,* In Press.
3. R. D. Cess, M. H. Zhang, B. A. Wielicki, D. F. Young, X. L. Zhou, and Y. Nikitenko: The Influence of the 1998 El Nino upon Cloud-Radiative Forcing over the Pacific Warm Pool, *J. Climate,* Submitted.
4. Y. P. Zhou and R. D. Cess: Validation of longwave atmospheric radiation models using Atmospheric Radiation Measurements (ARM) data, *J. Geophys. Res.*, Submitted.
5. Y. P. Zhou and R. D. Cess: Algorithm-development strategies for retrieving the downwelling longwave flux at the Earth's surface, *J. Geophys. Res.,* Submitted.

ALGORITHM FOR EVALUATING THE SURFACE DOWNWARD LONGWAVE (SDLW) AS EVALUATED FROM DATA FOR SIX IOPS AT THE SGP AND APPLIED TO DATA FOR NINE SUBSEQUENT IOPS.

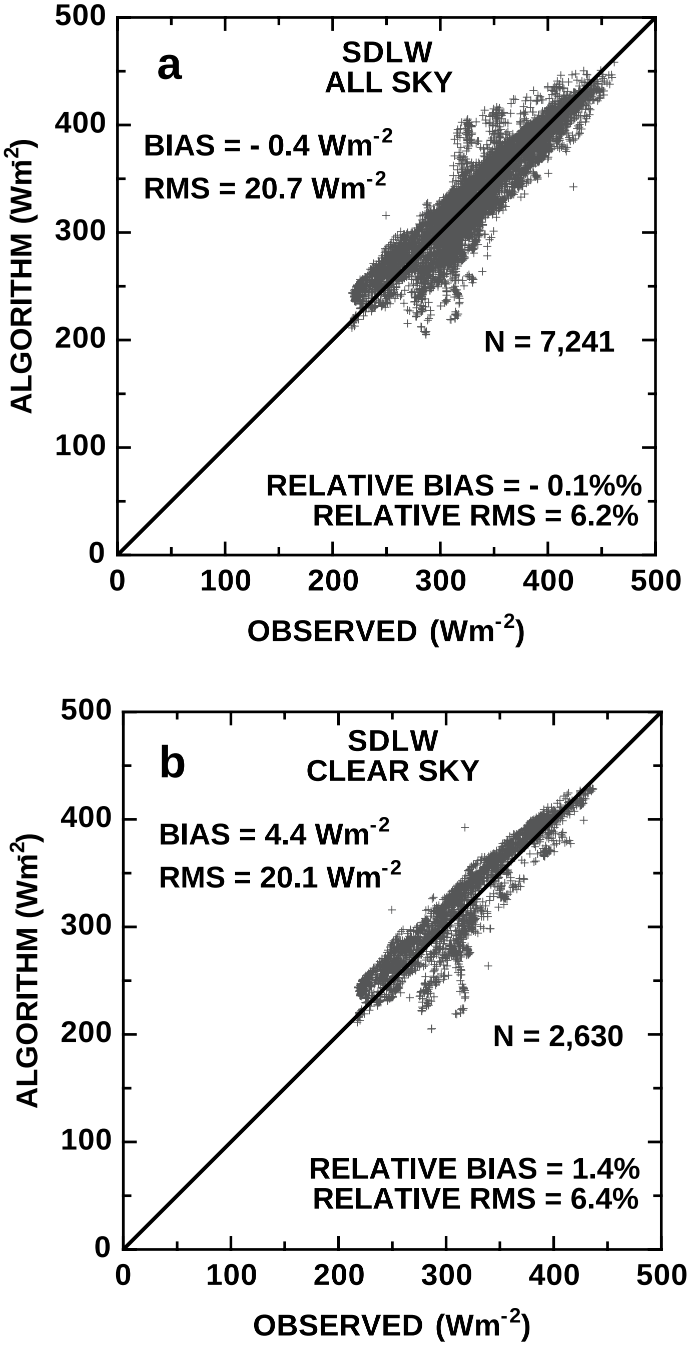


Figure 1

ALGORITHM FOR EVALUATING THE SURFACE DOWNWARD LONGWAVE (SDLW) AS EVALUATED FROM DATA FOR SIX IOPS AT THE SGP AND APPLIED TO DATA FOR TWP MANUS.

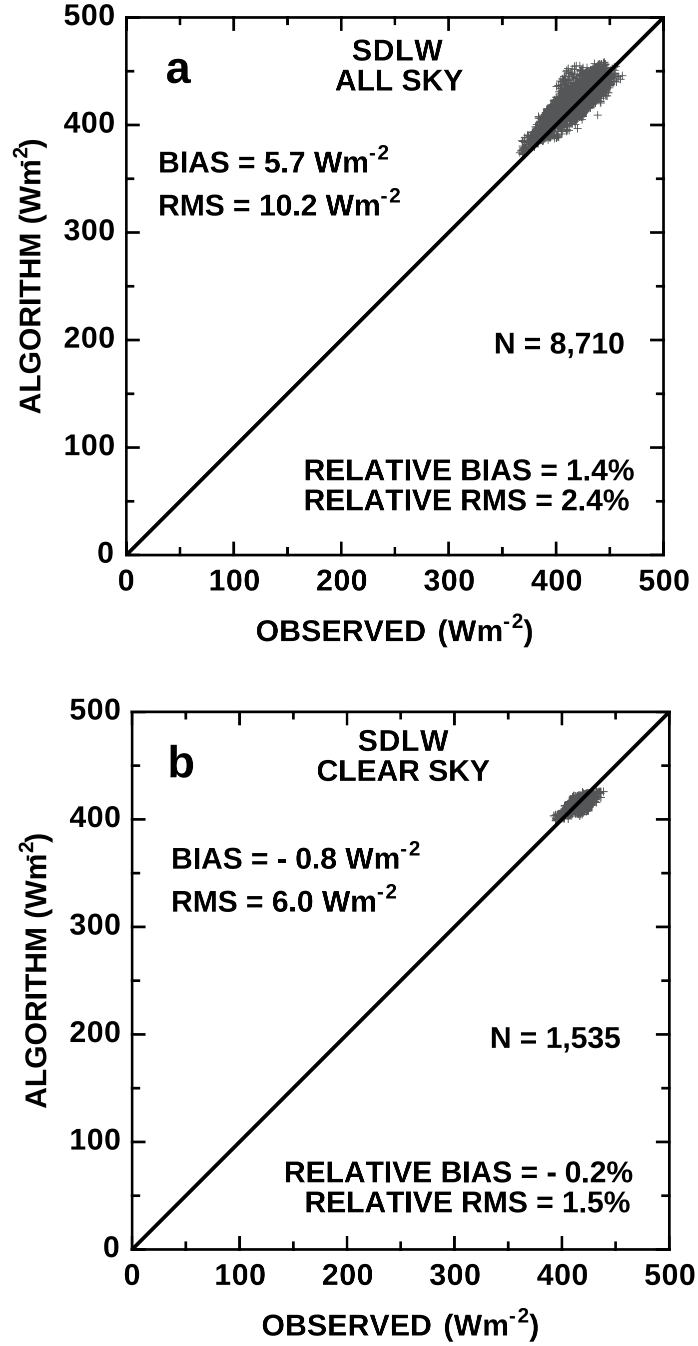
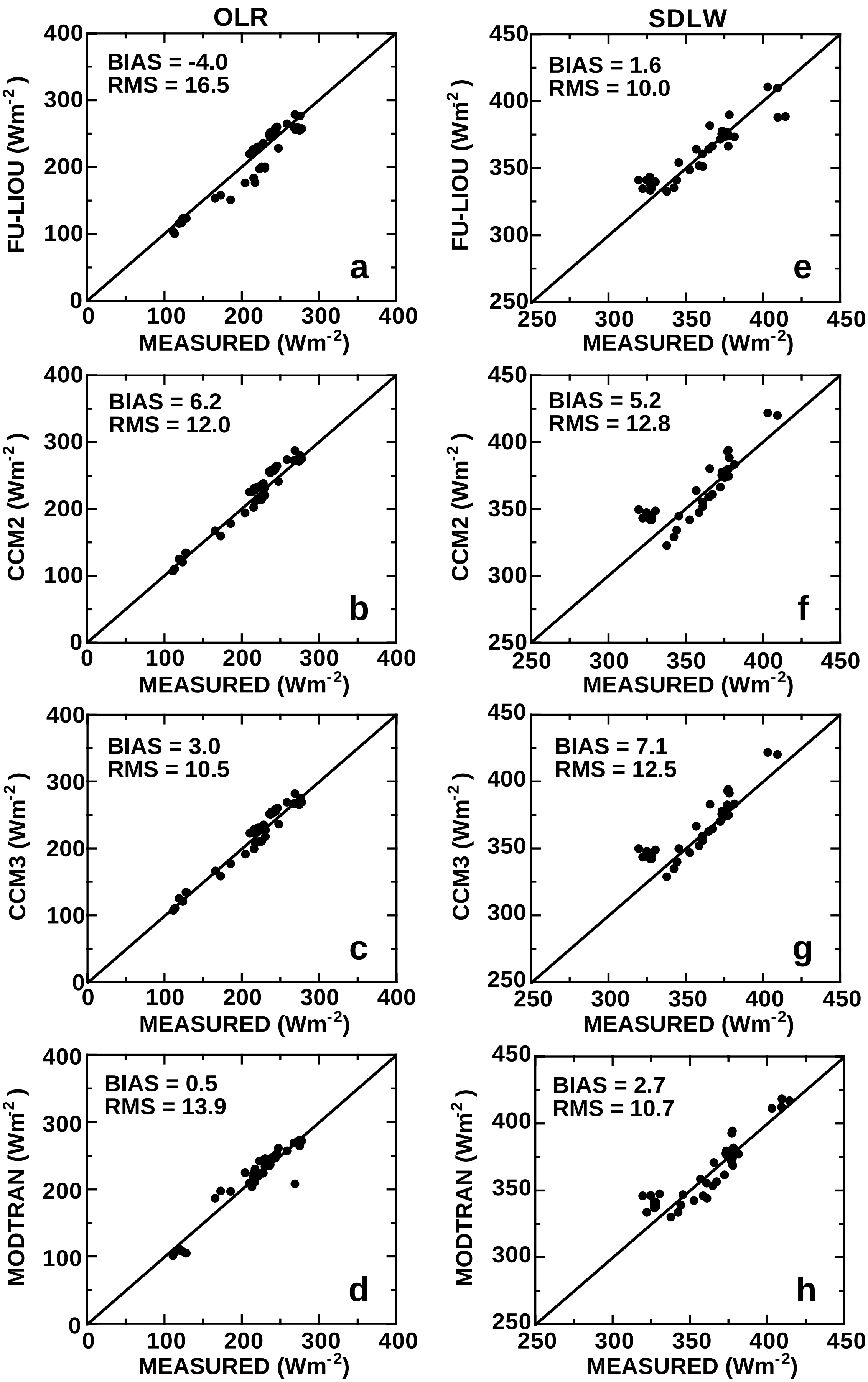


Figure 2



OLR
SDLW
BIAS = -4.0
RMS = 16.5
a
FU-LIOU (Wm-2)
BIAS = 1.6
RMS = 10.0
e
BIAS = 6.2
RMS = 12.0
b
CCM2 (Wm-2)
BIAS = 5.2
RMS = 12.8
f
BIAS = 3.0
RMS = 10.5
c
CCM3 (Wm-2)
BIAS = 7.1
RMS = 12.5
g
BIAS = 0.5
RMS = 13.9
d
MODTRAN (Wm-2)
BIAS = 2.7
RMS = 10.7
h
MEASURED (Wm-2)

Figure 3